Injury epidemiology and risk factors in competitive artistic gymnasts: a systematic review

Rhiannon A Campbell,[1,2] Elizabeth J Bradshaw,[3,4] Nick B Ball,[1,5] David L Pease,[2] Wayne Spratford[1,5]

[1]University of Canberra Research Institute of Sport and Exercise, University of Canberra, Canberra, Australian Capital Territory, Australia
[2]Applied Technology and Innovation, Australian Institute of Sport, Canberra, Australian Capital Territory, Australia
[3]Centre for Sport Research, School of Exercise and Nutrition Sciences, Deakin University, Melbourne, Victoria, Australia
[4]Sports Performance Research Institute New Zealand, Auckland University of Technology, Auckland, New Zealand
[5]Discipline of Sport and Exercise Science, Faculty of Health, University of Canberra, Bruce, Australian Capital Territory, Australia

Correspondence to
Miss Rhiannon A Campbell, University of Canberra Research Institute of Sport and Exercise, University of Canberra, Bruce ACT 2617, Australia; rhiannon.campbell@ausport.gov.au

Accepted 27 December 2018

To cite: Campbell RA, Bradshaw EJ, Ball NB, *et al*. *Br J Sports Med* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/bjsports-2018-099547

ABSTRACT

Background Artistic gymnastics is reported to have some of the highest injury rates in sports, which limits participation and often involves considerable medical expenses.

Purpose To critically appraise the epidemiological literature on injury patterns and risk factors in competitive artistic gymnastics.

Study design Systematic review.

Methods Six databases were searched for articles that investigated injuries in competitive artistic gymnasts. Injury incidence, prevalence and risk factor data were extracted, alongside information on injury location, type, severity, nature and mechanism of injury. Quality and level of evidence were assessed using a modified Downs and Black quality index checklist and the Oxford Centre for Evidence-based Medicine guidelines.

Results The search identified 894 articles, with 22 eligible for inclusion. Descriptive analysis showed that injury incidence and prevalence varied from 0.3 to 3.6 injuries per gymnast (female=0.3–3.6, male=0.7) and 2.0–2.3 (female=2.0–2.3, male=2.0), respectively. Male gymnasts sustained mostly upper limb injuries, while female gymnast reported lower limb injuries. Floor was associated with the greatest number of injuries for both male and female gymnasts. Higher competitive level and exposure to competition were risk factors for gymnastics injury: age, body mass, body size, training duration and life stress were significant associated factors.

Conclusion Injury incidence and prevalence results are substantial among artistic gymnasts of all competitive levels. Gymnasts who train at highly competitive levels and are exposed to competition environments are a greater risk of injury. Future researchers should implement consistent reporting methods.

INTRODUCTION

Artistic gymnastics is an Olympic sport in which men and women perform routines on a variety of different apparatus with the aim of obtaining the highest possible score. Female artistic gymnasts compete on four apparatus (vault, uneven bars, beam and floor), while male artistic gymnasts perform on six apparatus (floor, pommel, rings, vault, parallel bars and the horizontal bar). Gymnasts typically begin training as young as 6 years of age and can train up to 36 hours a week.[1] Competitive gymnasts have a high risk of sustaining an injury.[1]

Injury rates for artistic gymnasts have ranged from 1.5 to 9.2 injuries per 1000 athletic exposures (AEs; one AE is equivalent to one gymnast participating in one training session or competition).[2–5] In the American collegiate sports system (inter-university sporting competitions), women's artistic gymnastics was reported to have the second highest prevalence proportions (6.1 injuries per 1000 AE), ranking second behind men's American football (9.6 injuries per 1000 AEs).[5] Additionally, women's gymnastics had one of the highest prevalence results of stress fractures (25.6 per 100 000 AEs), only behind women's cross country running (28.6 per 100 000 AEs).[6]

Injury can have a multitude of adverse effects, including reduced sport participation time,[7] risk of degenerative musculoskeletal disorders,[7] risk of long-term or permanent disability,[8] increased risk for reinjury,[2 9] decreased well-being[10] and associated medical expenses.[11] When designing injury prevention programmes, injury surveillance is a critical step in order to provide clear information on the type, location and severity of injuries that are likely to occur in a given sport.[12 13] This information assists with identifying high-risk patterns where future interventions may focus, in order to have the greatest impact in reducing injury risk.[13] Previous narrative reviews have been published on gymnastics injuries[1 14–19]; however, none have taken a systematic approach. In this systematic review, we aimed to critically appraise the available literature on the incidence, prevalence, location, type, severity, mechanism and risk/associated factors of injuries in competitive male and female artistic gymnasts.

METHODS

Data sources and search strategy

This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[20] A comprehensive literature search of six relevant electronic databases (CINHAL complete, MEDLINE complete, SPORTDiscus, Scopus, PubMed and Web of Science) was conducted from their origin to 12 July 2018. Search terms were piloted to ensure the most comprehensive identification of articles for this systematic review. The following keyword string was used to search in each database: '(gymnast* OR 'artistic gymnast*') AND (injur* OR fracture* OR sprain* OR strain* OR ligament*) AND ('risk factor*' OR overuse OR 'training load' OR maturation)'. Gymnastics, sprains and strains and risk factor are all Medical Subject Headings (MeSH terms). Limits of the search were set to only include peer-reviewed articles (this filter was not available for MEDLINE, Scopus, PubMed and Web of Science) that are available in English. No limit was placed on publication date to provide the most comprehensive summary of injury patterns experienced in competitive artistic gymnasts.

Study selection

Articles identified through the database search were title/abstract screened independently by two authors (RC and WS) based on a priori inclusion and exclusion criteria. Full-text screening was conducted independently by two authors (RC and WS), and all disagreements were resolved by consensus. The reference lists of all included articles and review articles (prior to exclusion) were screened to identify additional relevant articles. If further information was needed to determine if articles met the inclusion criteria, the authors were contacted to clarify details about their study. If no response was received, the article was excluded.

Inclusion criteria

Studies were eligible for inclusion if they: (1) investigated injury incidence (number of new injuries that occurred to the population during a specific duration of time), injury prevalence (proportion of population who have an injury at a specific time), risk factors (when temporality is considered; ie prospective cohort studies) or associated factors (where temporality cannot be assessed; ie cross-sectional studies)[21 22] in competitive artistic gymnasts, (2) were original research articles, (3) had been through an independent peer-review process and (4) were available in the English language.

Associated factors are identified through cross-sectional and some retrospective studies that observe a difference between two groups at a specific period in time, but are unable to classify whether the factors are predisposing or causative factors because of the design of the study. Specifically, these study designs cannot distinguish whether exposure to the factor came before or after the observed outcome; therefore, they can only identify associated factors.[23–25] Prospective research designs consider temporality and can therefore identify risk factors.[24 25]

For this review, a gymnast was considered 'competitive' if they competed in competitions at a club (competed in local competitions), state/provincial (competed at state/provincial championships), national (competed at national championships), collegiate (competes within the collegiate system) or international level (competed at major international competitions). Studies where competitive artistic gymnasts' data could be analysed separately from other athletes were also included. For randomised control trials, only the pre-intervention data were considered for analysis as the post-intervention results would have been altered by the intervention undertaken. No limits were placed on the age of the participants.

Exclusion criteria

Studies were excluded if they: (1) were any type of review article (reference lists were screened prior to exclusion), case study or conference abstract, (2) investigated other forms of gymnastics (eg, rhythmic, aerobic, acrobatic or trampoline), (3) included recreational artistic gymnasts in the participant population, (4) recruited participants from school gymnastics teams (primary, middle or high school) or (5) reported primarily on anatomical variations (eg, ulnar variance) rather than injuries. Studies where gymnasts were recruited from school teams were excluded because school gymnastics differs greatly from competitive club gymnastics. School gymnastics teams tend to train sporadically and generally employ less experienced coaches, while competitive club gymnasts will train all-year round with coaches having to partake in extensive training.[26] It is also difficult to determine if the recorded injuries occurred in physical education classes while participating in gymnastics activities, or during school-based gymnastics team training.

Quality assessment and level of evidence

Quality assessment was conducted using a modified version of the Downs and Black (D&B) quality index checklist. Areas of assessment include the quality of reporting, external validity, risk of bias, confounding bias and power. This checklist was selected as it is specifically designed to be modified to assess the quality of observational studies.[27–29] Checklist items 4, 8, 13, 14, 15, 17, 19, 21, 23 and 24 were removed as these were inappropriate for the observational designs of the studies included in this review. Examples of the removed items include, 'Was an attempt made to blind study subjects to the intervention they received?' and 'Were study subjects randomised to intervention groups?' Additionally, items 3, 9, 10, 20 and 27[30] were customised as these items are topic sensitive, so reviewers were provided with additional information (eg, known confounders) to make the interpretation of the items much clearer.[27] For example, item 3 was adapted from, 'Are the characteristics of the participants included in the study clearly described?' to include the minimal information acceptable to gain a point for this item (must include the age, height and mass of the participants). Additionally, item 9 was altered from, 'Have the characteristics of participants lost to follow-up been described?' to also include information for studies that used surveys and detailed that response rates must be reported to score a point for this item. Each study could score a maximum of 19 points, and articles that scored 10 or less points (approx. <50%) were excluded from the review. The cut-off threshold was similar to previous systematic reviews[29 31 32] and ensured that only the highest quality articles were included in this review.

Level of evidence (LoE) was assessed using the Oxford Centre for Evidence-based Medicine guidelines (OCEBM).[33] The OCEBM guidelines provide five different levels of evidence scores based on study design and how well each controls for bias. Level 1 is the highest level of evidence that includes high-quality systematic reviews or local and current random sample studies, and level 5 is the lowest and includes studies that report expert opinions. Two reviewers (RC and WS) independently assessed the quality and the level of evidence of each article and any disagreements (where the two reviewer's scores differed greater than 10%) was resolved through discussions until consensus was reached.

Data extraction and analysis

Data from all included studies were mined using a structured data extraction table. The data extraction table included information on authors, year, country, study design, surveillance period, population (sample size, sex, age, height, mass, gymnastics level and weekly gymnastics training hours), injury definition, data collection method, risk factors investigated, statistical analysis performed, injury incidence and prevalence (eg, injuries per gymnast, injuries per 1000 hours of gymnastics exposure and injuries per AE), injury location (eg, upper limbs), injury type (eg, sprains and fractures), injury severity (eg, days lost to injury), injury nature (eg, acute/overuse injuries and recurrent injuries) injury mechanism (eg, apparatus/gymnastics skills performed at time of injury), significant risk factors for injury, D&B quality index score and the OCEBM level of evidence score. Participants from each study were grouped according to sex and competitive gymnastics level. The following competitive level categories were used to allow comparison; club level (gymnasts who competed in local competitions representing their club), state level (gymnasts who were eligible to compete at state/provincial championships), national level (gymnasts who were eligible to compete

at national championships), collegiate level (gymnasts training and competing within the college system) or elite level (gymnasts who were eligible to be selected for national teams/compete at major international competitions). Extracted results from each of the studies were descriptively analysed. A meta-analysis could not be performed because all studies varied significantly in their reporting methods and analysis techniques.

RESULTS

Search results

The initial electronic database search yielded 815 articles. An additional 79 articles were identified through screening reference lists. Once duplicates were removed, a total of 432 articles were title/abstract screened, leaving 89 articles remaining for full-text assessment. Screening by full text left 56 potentially eligible articles, which were then quality assessed. At the end of this process, 22 articles were eligible for inclusion in this review (figure 1).

Study characteristics

Six of the included studies had a prospective cohort study design,[2 9 34–37] two studies used a cross-sectional design,[38–40] six implemented a cross-sectional and retrospective design[40–45] and eight used a retrospective cohort study design.[6 39 41 46–52] The 22 included studies were from nine different countries. Sixteen of the studies only investigated female artistic gymnasts,[2 6 9 35–38 43–45 47–52] three investigated male artistic gymnasts (or only the male gymnasts data could be included),[34 40 42] while the remaining three studies investigated both male and female artistic gymnasts.[39 41 46]Table 1 provides additional information on sample size, duration of surveillance period and participant characteristics.

Quality assessment and level of evidence

Quality assessment scores of all included studies ranged from 10.5 to 13 out of a possible 19 points (table 1). Included studies generally scored well in the reporting and the risk of bias sections, while most scored moderately to poorly in the confounding bias section. Half of the included studies scored very well in the external validity section, while the other half scored poorly. All but one study scored zero in the power analysis section. Studies had to score greater than 10 points (>50%) to be included in this review, and as a result, 32 articles were excluded due to poor quality (figure 1). Most excluded studies scored very poorly in the external validity and power sections, with majority scoring zero in both sections. The level of evidence scores for the studies included in this review ranged between 1 and 3. One paper received an evidence score of 1,[43] while all other studies (n=21) received a score of 3 (table 1).[2 6 9 34–42 44–52] No studies were scored as level 2 or 4, because these included systematic reviews and case-series studies, respectively, which were excluded from this review.

Injury definition and data collection methods

Injury definition and data collection methods varied significantly across the included studies (table 2). Three injury definitions required medical professionals to provide a diagnosis,[37 39 46] five required gymnasts to report injuries to an athletic trainer or coach,[6 47–49 52] one noted refraining from using a specific body part for longer than a day,[36] one recorded reports of pain[34] and 11 required gymnasts to miss or modify aspects of their training.[2 9 34 35 40 42–45 50 51] Data collection methods also significantly varied: 13 studies used self-report injury reports/diaries/questionnaires,[2 9 34–38 41 43–45 50 51] four used interview methods,[2 9 40 42] five required injuries to be reported by coaches or athletic trainers[6 47–49 52] and four required a diagnosis from a medical professional.[37–39 46]

Injury incidence and prevalence

A total of 21 studies reported injury data: six studies reported injury incidence,[2 9 34–37] while 15 studies described injury prevalence (table 2).[6 38–49 51 52] Among the studies that reported all injuries, the one-year incidence of injuries to female gymnasts ranged between 2.5 and 3.6 injuries per gymnast[9 35] or 3.7 injuries per 1000 hours[9], while over a three-year period, it was reported as 0.3 injuries per gymnast[36] or between 0.5–2.5 injuries per 1000 hours of exposure.[2 36] The injury incidence rate for male gymnasts was reported as 0.7 injuries per gymnasts per season or 1.0 injury per 1000 hours.[34]

The one-year prevalence proportions for female gymnasts was reported as 2.0 injuries per gymnast[46 51] or 2.0 injuries per 1000 hours of exposure,[51] while over four years, the prevalence was revealed to be 2.3 injuries per gymnast.[45] Prevalence of injuries for male gymnasts was reported as 2.0 injuries per gymnasts per year.[46] Table 2 also reports the incidence and prevalence results for studies that focused primarily on wrist injuries,[41 42] ankle injuries,[40] elbow injuries,[38 48] stress fractures,[6 37] severe injuries,[49] ACL injuries,[47] deltoid ligament sprains[52] and spondylosis.[39]

Injury location

Eleven studies provided information on the distribution of the anatomical location of gymnastics injuries (table 3).[2 6 9 34–36 40–46 49 51] Ten studies investigated the location of injuries to female gymnasts, all of which reported the lower limbs (or a specific location within the lower limbs) as the most commonly injured area of the body.[2 6 9 35 36 43 44 46 49 51] For male gymnasts, only two studies reported the location of injuries, and both stated the upper limbs as the most commonly injured area.[34 46] Additionally, four studies focused on injuries that only occurred at the wrist,[41 42] ankle[40] and elbow[38] (table 2).

Injury type

Twelve studies provided information on the type of injuries sustained throughout their respective surveillance periods (table 3).[2 9 35 36 38 40–43 46 49 51] Eight studies reported on the injury type for female gymnasts, of which five mentioned either strains or sprains as being the most common injury type.[2 35 43 49 51] Non-specific pain,[9] fractures[36] and lumbosacral soft tissue/pars defects[46] were also listed as common for female gymnasts. Only one study reported on male gymnasts injury type and identified that shoulder rotator cuff lesions were most common.[46]

Four studies provided detailed information about specific types of injuries sustained at the elbow,[38] wrist[41 42] and ankle (table 3).[38 40 42] Gymnasts experienced mostly pain at the elbow (20.0%),[38] while the majority of wrist injuries were aching pains (92.0%)[41] or wounds (47.0%)[42] and ankle injuries mostly involved the joint or ligaments (79.0%).[40] Additionally, six studies focused only on the presence of stress fractures,[6 37] ACL injuries,[47] elbow subluxation and dislocations,[48] deltoid ligament sprains[52] and spondylolysis (table 2).[37 39]

Injury severity

Twelve studies provided an indication of the severity of the reported injuries (table 3).[2 9 34–36 40 41 43 44 46 51 52] Most studies described injury severity by reporting either the number of training

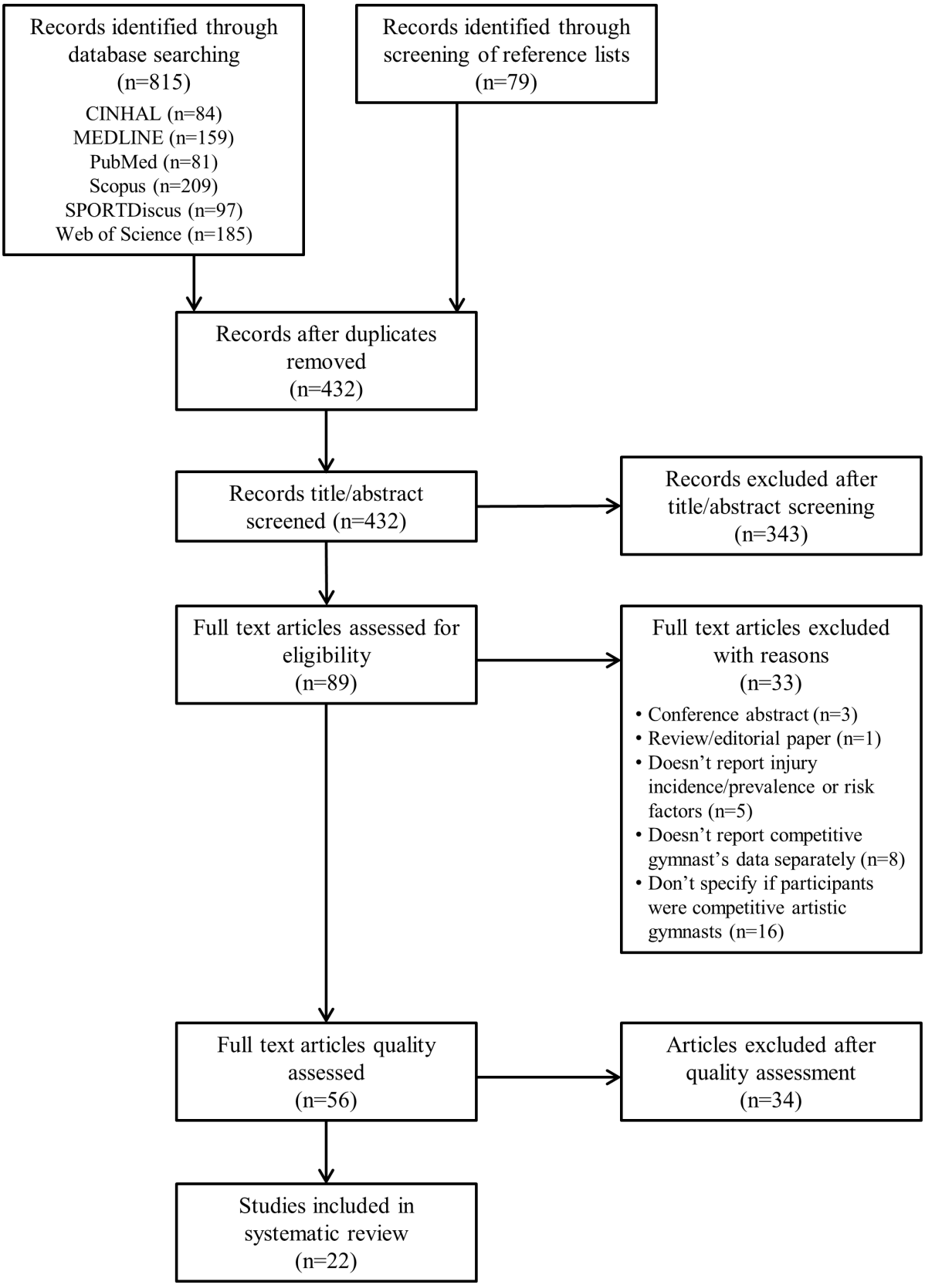

Figure 1 PRISMA flow chart of included and excluded studies. PRISMA, Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols.

Table 1 Study characteristics

Authors, year (country)	Study design, surveillance period, injury location/type investigated	Sample size, mean age, height and body mass (M, F; SD/range)	Level of competition, mean/range training exposure±SD (range)	D&B score, OCEBM LoE
Bak *et al*,[34] 1994 (Denmark)	Prospective cohort. 1 year. Whole body injuries.	37 M. 16 (8–23) years. 167 (127–191) cm. 58 (26–93) kg.	Elite and national levels. 14 (5–27) hours/week, 49 (47–51) weeks/year.	11. Level 3.
Caine *et al*,[9]1989 (USA)	Prospective cohort. 1 year. Whole body injuries.	50 F. 12.6 years. Height and body mass not reported.	Elite, national and state level. 20–27 hours/week, 5–6 days/week.	13. Level 3.
Caine *et al*,[2] 2003 (USA)	Prospective cohort. 3 years. Whole body injuries.	79 F. 7–18 years. Height and body mass not reported.	National, state and club level. 7.5–22.5 hours/week, 3–6 days/week.	13. Level 3.
Dexel *et al*,[38] 2014 (Germany)	Cross-sectional. Elbow injuries.	30 F. 11.7 years. Height and body mass not reported.	National level. 7.8±1.3 sessions/week.	11. Level 3.
DiFiori *et al*,[41] 1996 (USA)	Cross-sectional and retrospective. 6 months. Wrist injuries.	52 (20 M, 32 F). M: 10.9±3.3 years; F: 12.3±2.0 years Height and body mass not reported.	National, state and club levels 11.9±5.2 hours/week.	11.5. Level 3.
Dixon and Fricker,[46] 1993 (Australia)	Retrospective cohort. 10 years. Whole body injuries.	116 (42 M, 74 F). M: 16.5 years; F: 13.5 years (at beginning of scholarship). Height and body mass not reported.	Elite level. 36–40 hours/week, 11–12 sessions/week.	11. Level 3.
Gans *et al*,[47] 2018 (USA)	Retrospective. 10 years. ACL injuries.	F only (number not reported). Age, height and body mass not reported.	Collegiate level. Training exposure not reported.	11. Level 3.
Ghasempour *et al*,[40] 2013 (Iran)	Cross-sectional and retrospective. 1 year. Ankle injuries.	43 M. 20.5 (16–28) years. Height and body mass not reported.	Elite level. 2.7 hours/session, 5.3 sessions/week.	11.5. Level 3.
Ghasempour *et al*,[42] 2014 (Iran)	Cross-sectional and retrospective. 1 year. Wrist injuries.	43 M. 20.5 (16–28) years. Height and body mass not reported.	Elite level. 2.7 hours/session, 5.3 sessions/week.	13. Level 3.
Goodman *et al*,[48] 2018 (USA)	Retrospective cohort. 4 years. Elbow subluxation and dislocation injuries.	F only (number not reported). Age, height and body mass not reported.	Collegiate level. Training exposure not reported.	10.5. Level 3.
Kay *et al*,[49] 2017 (USA)	Retrospective cohort. 5 years. Severe injuries.	F only (number not reported). Age, height and body mass not reported.	Collegiate level. Training exposure not reported.	12. Level 3.
Kolt and Kirkby,[51] 1995 (Australia)	Retrospective cohort. 1 year. Whole body injuries.	162 F. 12.6±2.0 years. Height and body mass not reported.	Elite, national and state level. Elite: 31.1±3.6 hours/week; national/state: 17.0±4.6 hours/week.	12. Level 3.
Kolt and Kirkby,[50] 1999 (Australia)	Retrospective cohort. 1 year. Whole body injuries.	162 F. 12.6±2.0 years. Height and body mass not reported.	Elite, national and state level. Elite: 31.1±3.6 hours/week; national/state: 17.0±4.6 hours/week.	11.5. Level 3.
Kolt and Kirkby,[35] 1999 (Australia)	Prospective cohort. 18 months. Whole body injuries.	64 F. 12.6±1.7 years. Height and body mass not reported.	Elite, national and state level. Elite: 33.3±2.4 hours/week; national/state: 16.8±4.5 hours/week.	11. Level 3.
Kopec *et al*,[52] 2017 (USA)	Retrospective cohort. 5 years. Deltoid ligament sprains.	F only (number not reported). Age, height and body mass not reported.	Collegiate level. Training exposure not reported.	10.5. Level 3.
Lindner and Caine,[36] 1990 (Canada)	Prospective cohort. 3 years. Whole body injuries.	178 F. 7–15 years. Height and body mass not reported.	National and state level. Training exposure not reported.	11.5. Level 3.
O'Kane *et al*,[43] 2014 (USA)	Cross-sectional and retrospective. Entire gymnastics career and last season. Whole body injuries.	96 F. 7–17 years. Height and body mass not reported.	National and state level. Training exposure not reported for entire sample or subgroups.	11. Level 1.
Rizzone *et al*,[6] 2017 (USA)	Retrospective cohort. 10 years. Stress fractures.	F only (number not reported). Age, height and body mass not reported.	Collegiate level. Training exposure not reported.	10.5. Level 3.
Soler and Calderon,[39] 2000 (Spain)	Cross-sectional. Spondylolysis.	112 M and F. Age, height and body mass not reported.	Elite level. Training exposure not reported.	12. Level 3.

Continued

Table 1 Continued

Authors, year (country)	Study design, surveillance period, injury location/type investigated	Sample size, mean age, height and body mass (M, F; SD/range)	Level of competition, mean/range training exposure±SD (range)	D&B score, OCEBM LoE
Tenforde *et al*,[37] 2017 (USA)	Prospective cohort. Surveillance period not reported. Stress fractures.	16 F. Age, height and body mass not reported.	Collegiate level. Training exposure not reported.	13. Level 3.
Vanderlei *et al*,[44] 2013 (Brazil)	Cross-sectional and retrospective. 1 year. Whole body injuries.	8 F. Age, height and body mass not reported.	National and state level. Training exposure not reported.	13. Level 3.
Wright and De Cree,[45] 1998 (UK)	Cross-sectional and retrospective. 4 years. Whole body injuries.	15 F. 11.8±3.5 years. Height and body mass not reported.	Elite level. 13.6±5.8 hours/week.	13. Level 3.

D&B, Downs and Black; F, female; LoE, Level of Evidence; M, male; OCEBM, Oxford Centre for Evidence-based Medicine.

sessions, days, weeks or months lost to injury.[2 9 35 36 40 43 44 46 51 52] However, one study reported the duration of pain,[41] and another used a grading system based on subjective reports on pain, as well as subsequent modified aspects of training.[34] Furthermore, one study only investigated severe injuries (restricted participation >21 days; table 2).[49] It should be noted that there were no catastrophic or life-threatening injuries reported in any of the included studies.

Injury nature

Seven studies provided information on whether the injury was acute or overuse in nature.[2 6 9 36 44 47 52] The incidence of reported acute injuries for female gymnasts ranged from 55.8%-83.3%, whereas overuse injuries ranged between 23.3%-44.2%,[2 9 35 36] while the prevalence of acute and overuse injuries varied from 58.3%–73.5% and 26.5%–41.7%, respectively.[45 46 51] Only two studies reported on the nature of male gymnasts' injuries; the incidence for acute injuries was reported as 73.0% and overuse injuries as 27.0%,[34] while the acute injury prevalence was 60.3% and overuse 39.7%.[46] Additionally, one study reported the percentage of female gymnasts to sustain acute and overuse injuries over the previous season (acute=43.5%, overuse=40.7%) as well as over their lifetime of gymnastics activity (acute=57.6%, overuse=52.7%).[43]

Seven studies provided information on recurrent injuries.[2 6 9 36 44 47 52] The incidence of recurrent injuries ranged from 8.5% to 32.7%,[2 9 36] while the prevalence proportion ranged from 7.7% to 34.6% of all recorded injuries.[6 44 47 52] It should be noted that the highest recurrent rate was found for stress fractures,[6] while one of the lowest recurrent rates was recorded by Lindner and Caine,[36] who also found that 28% of gymnasts sustained a recurrent injury from an original injury they sustained prior to the surveillance period (which was not included in the recurrent rate during the surveillance period). Additionally, Caine *et al*[9] stated that 83.3% of all recorded recurrent injuries were from an original overuse injury.

Injury mechanism

Information on the mechanism of acute injury was provided by 10 studies[2 9 34 36 40 43–45 48 49 52]: five of which described the mechanism of injury,[36 44 48 49 52] seven reported the apparatus the injury occurred on[2 9 34 36 40 43 52] and four described either the skill phase or specific skill the gymnast was performing when injury occurred (table 4).[34 36 40 43] Surface contact was the most common injury mechanism,[48 49 52] and all but one study reported that floor was the apparatus associated with the greatest number of injuries for both male and female gymnasts (range 15.0%–58.0%).[2 9 34 36 40 43 52] However, two studies also reported that injuries were just as likely to occur on beam for female gymnasts[45 52] and parallel bars for male gymnasts.[34] In terms of the skill phase, landings were associated with the highest rates of injury (range 49%–76%),[40 43] followed by falls and collisions (27.8%).[34] Variations of leaps, jumps, swings, dismounts and tumbling skills were all mentioned as being associated with injury, but it should be noted that Lindner and Caine[36] stated that somersaults on floor were responsible for 24% of all injuries where a specific skill was mentioned.

Risk factors and associated factors

A total of two studies investigated risk factors,[2 9] while 10 studies investigated associated factors for gymnastics injury.[6 40–43 45 47 49 50 52] The distinction between risk factors and associated factors is outlined in the Methods. In short, we make the distinction because 'associations' identified in cross-sectional studies (and retrospective studies) should be interpreted differently from 'risk factors' identified in longitudinal studies.

Table 5 presents the significant risk and associated factors for gymnastics injury. Additional evidence exists to suggest that competitive level also influences the location and types of injuries for competitive female gymnasts. Two studies found that elite and national/state level female gymnasts most commonly sustained injuries to the lower limbs (range 50.5%–61.0%)[35 51]; however, one study found that national/state level gymnasts experienced more injuries to the spine and trunk region than elite gymnasts (22.0% and 11.2%, respectively).[35] In terms of injury type, Kolt and Kirkby[51] initially found that sprains were most common for both elite and national/state female gymnasts (32.4% and 28.1%, respectively). However, they later reported that that elite level gymnasts were more susceptible to growth-plate injuries (24.8%), while sprains were still most common for national/state level gymnasts (39.8%).[35] Furthermore, elite female gymnasts experienced an increased rate of overuse injuries (acute=44.1%–50.3%, overuse=49.7–55.9%), while national/state level female gymnasts sustained more acute injuries (acute=65.7%–75.0%, overuse=25.0–34.3%).[35 51]

DISCUSSION

Our systematic review highlights that there are large inconsistencies in the literature regarding how injury data in competitive artistic gymnasts is collected and reported. This is further discussed in the following sections along with the main injury findings.

Table 2 Injury definition, data collection methods, statistical analysis performed and injury incidence and prevalence

Authors, year (country)	Injury definition	Data collection method, statistical analyses performed	Injury incidence and prevalence
Bak *et al*,[34] 1994 (Denmark)	Any damage leading to pain, restriction in activity or completely preventing the subject from gymnastic activity.	Self-reported injury report. Descriptive statistics, Fisher's exact test, α=0.05 and 95% CI.	*Injury incidence* 0.7 injuries per gymnasts per season; 1.0 injuries per gymnast per 1000 hours.
Caine *et al*,[9] 1989 (USA)	Any gymnastics-related incident that resulted in a gymnast missing any portion of a workout or competitive event.	Baseline musculoskeletal assessment, self-reported training diaries and interviews. Descriptive statistics, canonical correlation analysis, stepwise discriminant analysis and discriminant function analysis.	*Injury incidence* 2.5 injuries per gymnast; 3.7 injuries per 1000 hours.
Caine *et al*,[2] 2003 (USA)	Any gymnastics-related incident that resulted in the gymnast missing any portion of a practice or competitive event, beginning on the day of injury.	Baseline musculoskeletal assessment, self-reported injury reports and interviews. Descriptive statistics, estimated risk ratios, Fisher's exact test and χ^2 test.	*Injury incidence* 2.5 injuries per 1000 hours; 8.5 injuries per 1000 AEs.
Dexel *et al*,[38] 2014 (Germany)	Not reported.	DASH questionnaire, MEPS questionnaire and MRI. Descriptive statistics and Fisher's exact test, α=0.05.	*Injury prevalence* 0.4 injuries per gymnast.
DiFiori *et al*,[41] 1996 (USA)	Not reported.	Survey and physical examination. Statistics analyses not reported.	*Injury prevalence* 0.7 injuries per gymnast.
Dixon and Fricker,[46] 1993 (Australia)	All injuries of the gymnasts that presented to the Australian Institute of Sport sports medicine department over the 10 years while training or competing were recorded. Injuries sustained prior to entering the programme but were still causing problems were also included.	Reviewed medical records. Descriptive statistics.	*Injury prevalence: female:* 2.0 injuries per gymnast per year; m*ale:* 2.0 injuries per gymnast per year.
Gans *et al*,[47] 2018 (USA)	An injury was defined as one resulting from participation in an organised intercollegiate practice or competition that required attention from a physician or athletic trainer. Primary ACL ruptures were defined as those occurring in knees with no history of ACL ruptures. Recurrent ACL ruptures were defined as those occurring in the same knee as a previously treated ACL rupture.	Reviewed NCAA-ISP medical records collected by athletic trainers. Descriptive statistics and ORs, α=0.05 and 95% CI.	*Injury prevalence* 34 injuries per 10 000 AEs.
Ghasempour *et al*,[40] 2013 (Iran)	Any damaged body part (only the ankle) that requires medical attention, prevents or restrict the gymnast from training or competing in any activity/apparatus in any way and/or any length of time.	Interviews and anthropometric measurements. Descriptive statistics, Spearman correlation and ETA method and α=0.05.	*Injury prevalence* 3.4 injuries per gymnast.
Ghasempour *et al*,[42] 2014 (Iran)	Any damaged body part (only to wrist) that required medical attention, prevented or restricted the gymnasts from training or competing in any activity/apparatus in any way and/or any length of time.	Interviews and anthropometric measurements. Descriptive statistics, Spearman correlation and coefficient of non-linear relationship (ETA) and α=0.05.	*Injury prevalence* 3.0 injuries per gymnast per year.
Goodman *et al*,[48] 2018 (USA)	All injuries that were reported to medical professional were recorded in the NCAA-ISP database. Injuries listed as elbow subluxation or elbow dislocation were included in the analysis.	Reviewed NCAA-ISP medical records collected by athletic trainers. Descriptive statistics and rate ratios and 95% CI.	*Injury prevalence* 0.7 injuries per 10 000 AEs.
Kay *et al*,[49] 2017 (USA)	A reportable injury occurred from participation in an organised intercollegiate practice or competition and required attention from an AT or physician. Severe injuries were those that restricted participation for more than 3 weeks (21 days). Severe injuries also included those that resulted in the student-athlete choosing to prematurely end the season, courses of recovery extending beyond the end of the season. and medical disqualification.	Reviewed NCAA-ISP medical records collected by athletic trainers. Descriptive statistics and rate ratios and 95% CI.	*Injury prevalence* 1.4 injuries per 1000 AEs.
Kolt and Kirkby,[51] 1995 (Australia)	A gymnastic-related incident that resulted in a participant missing or modifying any portion of a training session or competition.	Self-report questionnaire. Descriptive statistics, χ^2 test and t-tests with Bonferroni adjustment.	*Injury prevalence* 2.0 injuries per gymnast; 2.0 injuries per 1000 hours.
Kolt and Kirkby,[50] 1996 (Australia)	A gymnastic-related incident that resulted in a participant missing or modifying any portion of a training session or competition.	Self-report questionnaire. Multiple regression analysis, adjusted R^2 and correlations and 95% CI.	–
Kolt and Kirkby,[35] 1999 (Australia)	Any gymnastics-related physical damage that caused the gymnast to miss or modify one or more training sessions, competitions or both (not including blisters).	Self-report injury booklets. Descriptive statistics, χ^2 analysis and unpaired t-tests with Bonferroni adjustment.	*Injury incidence* 5.5 injuries per gymnast; 3.6 injuries per gymnast per year; 3.3 injuries per 1000 hours.

Continued

Table 2 Continued

Authors, year (country)	Injury definition	Data collection method, statistical analyses performed	Injury incidence and prevalence
Kopec *et al*,[52] 2017 (USA)	A reportable injury occurred from participation in an NCAA-sanctioned practice or competition and required attention from an AT or physician A specific definition of deltoid ligament sprain as they relied on the expertise of the ATs collecting data, as well as the other members of the team medical staff with whom they worked to accurately identify and diagnose such injuries.	Reviewed NCAA-ISP medical records collected by athletic trainers. Descriptive statistics, rate ratios and 95% CIs.	*Injury prevalence* 2.3 injuries per 10 000 AEs.
Lindner and Caine,[36] 1990 (Canada)	Defined as the inability to perform an activity requiring the use of a specific body part for longer than 1 day due to a physical complaint related to gymnastics.	Injury reports. Descriptive statistics.	*Injury incidence* 0.3 injuries per gymnast per year; 0.5 injuries per 1000 hours.
O'Kane *et al*,[43] 2014 (USA)	An acute injury was defined on the questionnaire as a sudden onset injury resulting in the inability to participate in at least 1 part of a practice or competition session for one or more days. An overuse injury did not require time loss but was defined as pain caused by gymnastics lasting 2 weeks or more, not resulting from an acute injury.	Self-report questionnaires. Descriptive statistics, χ^2 tests, multivariate regression modelling and 95% CIs.	*Injury prevalence* 1.3 acute injuries per 1000 hours; 1.8 overuse injuries per 1000 hours.
Rizzone *et al*,[6] 2017 (USA)	A reportable injury was defined as an injury that (1) occurred due to participation in a school-sanctioned practice or competition, (2) required attention from an AT or physician, (3) resulted in at least 24 hours of time missed from participation and (4) had a reported diagnosis of stress fracture.	Reviewed NCAA-ISP medical records collected by athletic trainers. Descriptive statistics, rate ratios and 95% CIs.	*Injury prevalence* 25.6 injuries per 100 000 AEs.
Soler and Calderon,[39] 2000 (Spain)	Athletes were deemed to have spondylolysis if images showed clear evidence of lysis in the lateral or oblique projections with or without listhesic sliding in the lateral radiographies. All doubtful cases were excluded.	Reviewed medical records and MRI. Descriptive statistics, independent t-test, Fisher-Snedecor test, Mann-Whitney U tests, χ^2 test and Fisher's exact test, α=0.05.	*Injury prevalence* 0.2 injuries per gymnast.
Tenforde *et al*,[37] 2017 (USA)	To be included as a BSI for a given athlete, the injury required diagnosis from a physician, imaging confirmation (MRI, CT, radiograph or bone scan) and documentation that the injury occurred as a result of sports participation.	Self-report questionnaire and DXA. Descriptive statistics, risk ratios, Poisson regression with robust standard errors and multivariate modelling.	*Injury incidence* 0.3 injuries per gymnast.
Vanderlei *et al*,[44] 2013 (Brazil)	Any physical complaint from training and/or competition that limited a subject's participation for at least 1 day was considered an injury from sports, regardless of the requirement of the medical care.	Self-report questionnaire. Independent t-tests, Mann-Whitney's test and Goodman's test, α=0.05.	*Injury prevalence* 1.3 injuries per gymnast.
Wright and De Cree,[45] 1998 (UK)	A gymnastics-related incident that limited participation in any of the gymnastic events.	Self-report questionnaire and anthropometric measurements. Multivariate analysis of variance, χ^2 tests and independent t-tests.	*Injury prevalence* 2.3 injuries per gymnast.

α, alpha significance level; AEs, athletic exposures; AT, athletic trainer; BSI, bone stress injury; DASH, disabilities of arm, shoulder and hand; DXA, duel X-ray absorptiometry; MEPS, Mayo Elbow Performance Score; NCAA-ISP, National Collegiate Athletic Association Injury Surveillance Program.

Quality assessment and level of evidence

The included studies in this systematic review scored relatively well in the reporting section (ie, describing target population); however, some studies missed critical information such as describing the age, height, body mass, training exposure information or the gymnasts competitive level. This made comparisons between studies, and the context of the findings, more difficult to interpret. The included studies generally scored moderate/poor in the confounding bias section (ie, reporting characteristics of participants lost to dropout). Half of the included studies scored full points in the external validity section (ie, how representative was the sample population of the entire population), while the other half scored poorly. Many of the articles that were excluded at the quality assessment stage did not provide enough information about the target population or did not use valid and reliable data collection and reporting methods. Overall, the quality of available gymnastics epidemiology literature is lacking. Specifically, more detailed descriptions of the sample population, reporting of confounding variables, participant dropout and providing reasons for dropout is greatly needed.

Twenty-one included studies were scored as having level 3 evidence (local non-random sample),[2 6 9 34–42 44–52] with only one study being scored level 1 (local and current random sample).[43] All but one study used some variation of convenience sampling: either recruiting from a single/few gymnastics clubs or medical clinics.[2 6 9 34–42 44–52] A greater emphasis should be placed on using random sampling methods (from different clubs and regions) to reduce sampling bias and provide a more accurate depiction of the burden of injury for competitive artistic gymnasts.

Injury definition and data collection methods

Injury definitions ranged from only capturing injuries that were diagnosed by a medical professional to gymnasts reporting their level of pain and discomfort. Generally, most injury definitions included aspects that accounted for missed or modified training/competitions,[2 9 34 35 40 42–45 50 51] and some sort of medical requirement.[37 39 46] Variation among data collection methods was also present; with few studies relying on medical records,[37–39 46] while others used diverse self-reported injury

Table 3 Summary of injury location, types and severity

Author, year (country)	Participants, types/location of injuries investigated	Most common injury locations (top three), n (%)	Most common injury types (top three), n (%)	Injury severity, mean/n (%)
Bak *et al*,[34] 1994 (Denmark)	Male gymnasts. Whole body injuries.	1. Upper limb=14 (53.8). 2. Lower limb=11 (42.3). 3. Back=1 (3.8).	–	Grade 1=19 (73.1). Grade 2=1 (3.8). Grade 3=5 (19.2). Grade 4=0 (0). Grade 5=1 (3.8). *Grade definitions presented in table footnote.
Caine *et al*,[9] 1989 (USA)	Female gymnasts. Whole body injuries.	1. Lower limbs=94 (63.7). 2. Upper limbs=30 (20.4). 3. Spine/trunk=22 (15.2).	1. Non-specific=59 (40.1). 2. Sprain=28 (19.0). 3. Strain=26 (17.7).	<8 days lost=60 (40.8). 8–21 days lost=49 (33.3). >21 days lost=38 (25.9).
Caine *et al*,[2] 2000 (USA)	Female gymnasts. Whole body injuries	1. Lower limbs=111 (57.8). 2. Upper limbs=41 (21.4). 3. Spine/trunk=37 (19.3).	1. Strain=61 (31.8). 2. Sprain=37 (19.3). 3. Other=27 (14.0).	<8 days lost=147 (76.6). 8–21 days lost=21 (10.9). >21 days lost=24 (12.5). Injuries that required surgery=9 (4.7).
Dexel *et al*,[38] 2014 (Germany)	Female gymnasts. Elbow injuries.	All elbow injuries.	*Elbow complaints at time of examination* 1. Pain=6 (20.0). 2. Blockage (recurring)=4 (13.4). 3. Swelling=2 (6.7). *MRI results* 1. No pathology=19 (63.4). 2. OCD (capitellum humeri)=7 (23.4). 3. Stress reaction=2 (6.7).	–
DiFiori *et al*,[41] 1996 (USA)	Male and female gymnasts. Wrist injuries.	1. Dorsal=61.5%. 2. Unknown=14%. 3. Ulnar=12.3%.	1. Aching=32 (92%). 2. Instability=18.4%. 3. Clicking, catching, swelling=all 5.0%.	Pain.>6 months=18 (47.0).
Dixon *et al*,[46] 1993 (Australia)	Male and female gymnasts. Whole body injuries.	*Men* 1. Upper limbs=133 (53.8). 2. Lower limbs=81 (32.8). 3. Spine=32 (13.0). *Women*[34 46] 1. Lower limbs=180 (54.4). 2. Upper limbs=86 (26.0). 3. Spine=65 (19.6).	*Men* 1. Shoulder rotator cuff lesions=42 (17.0). 2. Wrist impingement syndrome=26 (10.5). 3. Elbow soft tissue injuries=25 (10.1). *Women* 1. Lumbosacral soft tissue/pars defects=43 (13.2). 2. Foot/toes (stress fractures, ligament sprains, fat pad injury)=37 (11.4). 3. Ankle inversion injuries=36 (11.1).	Catastrophic/life threatening injuries=0. >2 months lost=9.
Ghasempour *et al*,[40] 2013 (Iran)	Male gymnasts. Ankle injuries.	All ankle injuries.	1. Torsion=81 (55.2). 2. Dislocation=25 (17.0). 3. Strain=25 (17.0).	Slight (1–3 days until return to full training)=50 (34.0). Minor (4–7 days)=74 (50.0). Moderate (8–28 days)=19 (13.0). Major (>28 days)=4 (3.0).
Ghasempour *et al*,[42] 2014 (Iran)	Male gymnasts. Wrist injuries.	All wrist injuries.	1. Wound=60 (47.0). 2. Inflammation=19 (15.0). 3. Wrist ganglia=19 (15.0).	Not reported.
Kay *et al*,[49] 2017 (USA)	Female gymnasts. Severe injuries.	1. Lower leg/ankle/foot=29 (36.7). 2. Knee=20 (25.3). 3. Elbow=10 (12.7).	1. Sprain=25 (31.6). 2. Strain=11 (13.9). 3. Fracture and other=both 9 (11.4).	All considered 'severe' injuries (restricted participation >21 days).
Kolt and Kirkby,[51] 1995 (Australia)	Female gymnasts. Whole body injuries.	1. Lower limbs=184 (57.3). 2. Upper limbs=73 (22.7). 3. Spine/trunk=57 (17.8).	1. Sprain=95 (29.6). 2. Strain=66 (20.6). 3. Growth plate=37 (11.5).	Mean training sessions missed=3.7. Mean number of training sessions modified=20.4. Mean weeks missed=0.7. Mean weeks modified=3.1.

Continued

Table 3 Continued

Author, year (country)	Participants, types/location of injuries investigated	Most common injury locations (top three), n (%)	Most common injury types (top three), n (%)	Injury severity, mean/n (%)
Kolt and Kirkby,[35] 1999 (Australia)	Female gymnasts. Whole body injuries.	1. Lower limb=205 (59.0). 2. Upper limb=74 (20.9). 3. Spine/trunk=60 (17.2).	1. Sprain=100 (29.7). 2. Strain=81 (23.2). 3. Growth plate=43 (12.3).	Mean training sessions missed=1.4. Mean number of training sessions=14.0. Mean weeks missed=0.4. Mean weeks modified=2.1.
Kopec *et al*,[52] 2017 (USA)	Female gymnasts. Deltoid ligament sprains.	Only deltoid ligament sprains.	Only deltoid ligament sprains.	Non-time loss=4 (30.8). Severe (>21 days lost)=2 (15.4).
Lindner and Caine,[36] 1990 (Canada)	Female gymnasts. Whole body injuries.	1. Lower limb=51 (53.1). 2. Upper limb=22 (22.9). 3. Spine/trunk=13 (13.5).	1. Fracture=21 (22.6). 2. Sprain=18 (19.4). 3. Strain and non-specific pain=both 11 (11.8).	<1 week lost=3 (3.4). 1 week lost=13 (14.8). 2 weeks lost=10 (11.4). 3 weeks lost=9 (10.2). 4 weeks lost=9 (10.2). 5 weeks lost=6 (6.8). 6 weeks lost=8 (9.1). >6 weeks lost=30 (34.1). Mean weeks lost=4.4.
O'Kane *et al*,[43] 2014 (USA)	Female gymnasts. Whole body injuries.	*Acute* 1. Foot=12 (21.0). 2. Ankle=11 (19.3). 3. Other=9 (15.8). *Overuse* 1. Other=16 (20.8). 2. Lower back=14 (18.4). 3. Foot=13 (17.2).	*Acute* 1. Sprain/strain=21 (39.6). 2. Bruise/swelling=16 (30.3). 3. Fracture=12 (22.6). *Overuse* Not reported.	*Acute* Mean days lost=25.2 (29.7 SD). Median days lost=14.0. *Overuse* Not reported.
Rizzone *et al*,[6] 2017 (USA)	Female gymnasts. Stress fractures.	1. Fibula=7 (26.9). 2. Metatarsal=7 (26.9). 3. Lower back/lumbar spine/pelvis=4 (15.4).	All stress fractures.	–
Vanderlei *et al*,[44] 2013 (Brazil)	Female gymnasts. Whole body injuries.	1. Lower limbs=7 (70.0). 2. Upper limbs=3 (30.0).	–	Light (1–7 restraining days)=9 (90.0). Moderate (8–21 restraining days)=1 (10.0).

*Grade 1=training with pain possible or minor restrictions in activity; grade 2=absence from training; grade 3=competing with pain or restrictions in exercise; grade 4=absence from training and competition and grade 5=hospital admission.

reports or questionnaires.[2 9 34–38 41 43–45 50 51] Depending on the injury definition and data collection method used, studies may have underestimated the true injury rate. For example, underestimation may occur if only injuries that required medical attention are recorded or studies that used self-report measures over long recall periods, which may introduce recall errors.[53] In contrast, others may have overestimated injuries, particularly those where gymnasts reported all types of pain and discomfort, which may be due to a training effect rather than an actual injury (eg, delayed onset muscle soreness). This highlights the influence that injury definitions and data collection methods can have on injury results and emphasises the need to implement consistent guidelines for future gymnastics epidemiology research in order for the results to be more conclusive.

Injury findings

Injury prevalence and incidence results shown in the current review have also been reported in previous narrative gymnastics reviews.[16 17 19 54] The results of this review are also comparative to dancing injury literature (another aesthetic sport), which has reported injury incidence ranging from 17% to 94%[55] and a prevalence from 3% to 100% of all dancers sustaining an injury.[55 56] For additional context, female artistic gymnastics is constantly reported as having some of highest injury rates in the American collegiate system, which includes sports such as soccer, football, volleyball, field hockey, basketball and lacrosse, some of which are considered contact or collision based sports.[6 47 48 52 57 58]

Distinct differences existed between male and female gymnasts in the anatomical location of injuries. Evidence suggests that female gymnasts sustain mostly lower limb injuries,[2 6 9 35 36 43–46 49 51] while males mostly injure their upper limbs.[34 46] These results seem logical considering female gymnasts compete on three apparatus (out of four; vault, beam and floor) that heavily use their lower limbs, while males compete on four apparatus (out of six; horizontal bar, parallel bars, pommel and rings) that mainly require the use of their upper limbs. Female gymnasts experienced mostly sprain or strain injuries,[35 45 51] while only one study described injury types for male gymnasts (rotator cuff lesions were most common).[46] Injury severity was defined in multiple ways (eg, missed training sessions and pain grading), with majority of studies reporting the duration until the gymnast returned to their former level of training as their primary definition.[2 9 35 36 40 44 51] However, there is evidence to suggest gymnasts return to their former level of training while still experiencing injury symptoms, which may explain the large variation between the reported injury severity results.[44]

Overuse injury results varied from 23.3% to 44.2% of all reported injuries for female gymnasts and between 27.0% and 39.7% for males. When compared with other sports, artistic gymnastics had a higher incidence of overuse ankle and foot injuries than basketball, rugby, soccer and volleyball athletes.[59] Additionally, a large epidemiological study found that gymnastics had some of the highest rates of overuse injury and deemed the sport a high overuse activity.[60] The high overuse injury rates

Table 4 Summary of acute injury mechanisms, apparatus and skills performed at time of injury

Author, year (country)	Participants, types of injuries investigated	Mechanism of injury, n (%)	Apparatus, n (%)	Skill phase, skill type/specific skill, n (%)
Bak *et al*,[34] 1994 (Denmark)	Male gymnasts. Whole body injuries.	–	Floor=4 (21.1). Pommel=2 (10.5). Rings=3 (15.8). Vault=1 (5.3). Parallel bars=4 (21.1). Horizontal bar=2 (10.5). Trampoline=1 (5.3). Other=2 (10.5).	Dismounts=4 (22.2). Falls=5 (27.8). Collision=5 (27.8). Mounts=0 (0). Other (gluing)=4 (22.2).
Caine *et al*,[9] 1989 (USA)	Female gymnasts. Whole body injuries.	–	Vault=9 (13.8). Uneven bars=13 (20.0). Beam=15 (23.1). Floor=23 (35.4). Other=5 (7.7).	–
Caine *et al*,[2] 2003 (USA)	Female gymnasts. Whole body injuries.	–	Vault=13 (11.4). Uneven bars=34 (29.8). Beam=19 (16.7). Floor=39 (34.2). Trampoline=3 (2.6). Other=6 (5.3).	–
Ghasempour *et al*,[40] 2013 (Iran)	Male gymnasts. Ankle injuries.	–	Floor=85 (58.0). Vault=43 (29.0).	Landing=112 (76.0). During routine (excluding landing)=35 (24.0).
Goodman *et al*,[48] 2018 (USA)	Female gymnasts. Elbow subluxation and elbow dislocations.	Surface contact=49 (100).	–	–
Kay *et al*,[49] 2017 (USA)	Female gymnasts. Severe injuries.	Surface contact=37 (46.8). Apparatus contact=16 (20.3).	–	–
Kopec *et al*,[52] 2017 (USA)	Female gymnasts. Deltoid ligament sprains.	Surface contact=8 (61.5).	Vault=3 (23.1). Beam=5 (38.5). Floor=5 (38.5).	–
Lindner and Caine, [36] 1990 (Canada)	Female gymnasts. Whole body injuries.	Apparatus failure=0 (0). Missed move=21 (30.0). Apparatus contact=12 (17.1). Fall from apparatus=11 (15.7). Dismount=8 (11.4). Contact with another Person=3 (4.3). Other=15 (21.4).	Vault=9 (13.0). Uneven bars=13 (18.8). Beam=12 (17.4). Floor=26 (37.7). No apparatus=9 (13.0).	*Vault* Handspring=5 (11.1). Tsukahara=2 (4.4). *Bars* Kip=3 (6.7.). Under-swing dismount=3 (6.7). Release=2 (4.4). *Beam* Walkover=2 (4.4). Back handspring=2 (4.4). Somersault dismount=2 (4.4). Aerial cartwheel=2 (4.4). *Floor* Round-off=6 (13.3). Back layout twisting somersault=4 (8.9). Back handspring=3 (6.7). Back somersault=4 (8.9). Back layout somersault=2 (4.4). Front somersault=3 (6.7).
O'Kane *et al*,[43] 2014 (USA)	Female gymnasts. Whole body injuries.	–	Vault=7 (13.2). Bars=9 (17.0). Beam=11 (20.7). Floor=17 (32.1). Other=9 (17.0).	Run-up phase=1 (2.1). Take-off phase=2 (3.9). Skill-specific phase=10 (19.6). Back handspring=3. Front handspring=2. Cast away from high bar=1. Jump to high bar=1. Heel snap turn=1. Straddle jump=1. Switch leap=1. Landings=25 (49.0). Other=13 (25.4).
Vanderlei *et al*,[44] 2013 (Brazil)	Female gymnasts. Whole body injuries.	Direct contact=0 (0). No contact=9 (90.0). Overload=1 (10.0).	–	–

Continued

Table 4 Continued

Author, year (country)	Participants, types of injuries investigated	Mechanism of injury, n (%)	Apparatus, n (%)	Skill phase, skill type/specific skill, n (%)
Wright andDe Cree,[45] 1998 (UK) Cross-sectional and retrospective.	Female gymnasts. Whole body injuries.	–	Vault=15.0%. Bars=15.0%. Beam 40.0%. Floor=15.0%.	–

in this review are particularly alarming, especially considering that these injuries could be reduced through adequate monitoring and prescription of training.[61] Few studies collected data on recurrent injury rates meaning results varied greatly (range 8.5%–34.6%).[2 6 36 44 47 52] Furthermore, up to 83% of recurrent injuries were from an original overuse injury.[9] However, it is likely the recurrent rate of injury may be higher than previously reported, because most studies only counted injuries as 'recurrent' if they occurred within the surveillance period.

Both men and women reported that floor was the apparatus associated with the greatest number of injuries. This result is consistent with other gymnastics reviews[1 7 16 17 54 62] and seems like a logical result, especially since gymnasts perform warm-up, strengthening exercises, practice skills for other apparatus as well as train floor routines on this apparatus. Landings were associated with the greatest number of injuries,[40 43] followed by falls and collisions,[34] which is a consistent result among the literature.[1 7 15–17 54] Many variations of skills were listed as causing injury; however it appears that tumbling skills on floor (specifically somersaults) were the most hazardous.[36] Interestingly, all the skills listed as associated with injury are relatively basic to moderate level skills. Previously it has been hypothesised that performing more advanced level skills would result in a greater number of injuries[16 17]; however, only two studies reported specific skills (and only included up to national level gymnasts), meaning that results are still unknown for higher level gymnasts (elite).

Risk factors and associated factors

This review suggests that gymnasts who are older,[41 45] taller,[45] heavier in body mass,[41 42 44] have a bigger body size,[40] are training at a higher competitive level,[9 41] training for longer durations,[41] competing at competitions[2 47 52] and are experiencing increased life stress[50] are at a greater risk for developing a gymnastics injury. Additionally, the competitive phase proved important for ACL injuries (greater risk during competition/post-season phase) and severe injury risk (greater risk during pre-season compared with competition phase).[47 49] No studies reported a significant relationship between menarcheal status and injury, although Caine *et al*[9] did observe a trend that suggested that postmenarcheal gymnasts were at a slightly greater risk for injury ($p<0.06$). The exact explanation for this is currently unknown; however, it has been suggested that premenarcheal gymnasts are generally smaller with greater skeletal plasticity, which may support why they sustain fewer injuries.[43] The identified risk and associated factors are very similar to dance literature findings, with age, training duration, psychosocial characteristics[55 56] and performance level[55] all being linked to dancing injuries. Clinicians and training staff should be aware of the above-mentioned risk and associated factors for gymnastics injury to identify and monitor gymnasts that meet these requirements. Gymnasts may need close medical supervision and regularly questioned about the presence of injury, especially as they mature and transition into higher competitive levels and begin to increase their training load.

Ideally, prospective cohort studies are best placed to identify potential risk factors for injury; however, only six studies used this design, while most were either retrospective or cross-sectional, therefore often ignoring the temporal association.[63] Additionally, many studies did not use random sampling methods or provide information on confounding variables, which may have skewed the results by either overestimating or underestimating the true association with injury.

Strengths and limitations

Several methods were employed to ensure the quality of this review. Initially, a total of six databases were searched using a thorough string of keywords, along with the screening of all reference lists to limit the number of eligible articles missed. Second, the articles were all independently screened by two reviewers at the title/abstract level and full-text level. Lastly, articles were quality assessed using a valid and reliable checklist tool[27] and were excluded from this review if they were not of sufficient quality. This ensured that only the best quality articles were included in this review.

However, this review does have several limitations. As mentioned previously, the different methodologies used in the included studies has made drawing conclusions between these studies difficult and reinforces the need for improved research design and analysis. A lack of random sampling methods was also present, which may have introduced some sampling bias into this review, potentially compromising the generalisability of these results to the entire population (ie, all competitive artistic gymnasts). This review also included studies that purely focused on specific types or locations of injuries (ie, ACL injuries and wrist injuries), which may provide an under-representation of the true extent of injury that occurred in those populations because only certain injuries were recorded. To address this issue, these studies were not grouped with studies that investigated all injuries but discussed separately to reduce this bias. Furthermore, most studies used self-reported measures that may be subject to recall error (if collected retrospectively) or may not have captured the true nature and diagnosis of the injury. Finally, comparisons between female and male gymnasts should be treated with caution as there were very few articles that explored injuries in competitive male artistic gymnasts.

Recommendations for future research

Future research should focus on improving the quality and level of evidence by using comparable data collection methods, such as using consistent injury definitions, standardised reporting of results and conducting validity and reliability tests on questionnaires. It is recommended that future gymnastics injury research use an injury definition that encompasses key points from injury definitions already in place for other sports, such as addressing time-loss from training/competition, modified aspects of training,

Table 5 Risk and associated factors for gymnastics injury

Authors, year (country), study design, injuries investigated	Risk factors investigated	Significant risk factors	Associated factors investigated	Significant associated factors
Caine *et al*,[9] 1989 (USA). Prospective cohort. Whole body injuries.	Maturation rate, somatotype, exposure time and competitive level.	1. Higher competitive level (p<0.05). 2. Trend towards maturation rate (p<0.06).	–	-
Caine *et al*,[2] 2003 (USA). Prospective cohort. Whole body injuries.	Competitive level and exposure to training/ competition.	1. Exposure to competition (compared with training, risk ratio=2.7, p=0.035).	–	-
DiFiori *et al*,[41] 1996 (USA). Cross-sectional and retrospective. Elbow injuries.	–	–	Age, height, body mass, training duration, competitive level, age at initiation of training and years of cumulative exposure.	1. Older age (p<0.05). 2. Greater body mass (p<0.05). 3. Longer training duration (p<0.05). 4. Higher competitive level (p<0.05).
Gans *et al*,[47] 2018 (USA). Retrospective cohort. ACL injuries.	–	–	Exposure to training/ competition and time of season.	1. Exposure to competition (compared with training; OR 6.1, 95% CI 2.7 to 13.0, p<0.0001). 2. Exposure to regular season/postseason training (compared with preseason; OR 2.5, 95% CI 1.0 to 6.0, p=0.04).
Ghasempour *et al*,[40] 2013 (Iran). Cross-sectional and retrospective. Ankle injuries.	–	–	Body mass, height, body mass index, somatotype, body fat percentage, lower extremity length, ankle girth, calf girth and body size (based on wrist circumference).	1. Larger body size (p=0.002).
Ghasempour *et al*,[42] 2014 (Iran). Cross-sectional and retrospective. Wrist injuries.	–	–	Height, body mass, body mass index, fat percentage, somatotype, body size, wrist girth and forearm girth.	1. Greater body mass (p=0.02).
Kay *et al*,[49]2017 (USA). Retrospective cohort. Severe injuries.	–	–	Exposure to training/ competition and time of season.	1. Exposure to preseason (compared with regular season, rate ratio=2.1, 95% CI 1.2 to 3.4).
Kolt and Kirkby,[50] 1996 (Australia). Retrospective cohort. Whole body injuries.	–	–	Life stress, anxiety, self-esteem and locus of control.	1. Increased life stress (95% CI 0.039 to 0.118).
Kopec *et al*,[52] 2017 (USA). Retrospective cohort. Deltoid ligament sprains.	–	–	Exposure to training/competition.	1. Exposure to competition (compared with training, rate ratio=8.5, 95% CI 2.9 to 25.4).
O'Kane *et al*,[43] 2014 (USA). Cross-sectional and retrospective. Whole body injuries.	–	–	Age, body mass index, menarcheal status, training duration and competitive level.	No significant findings.
Rizzone *et al*,[6] 2017 (USA). Retrospective cohort. Stress fractures.	–	–	Exposure to training/competition.	No significant findings.
Wright and De Cree,[45]1998 (UK). Cross-sectional and retrospective. Whole body injuries.	–	–	Age, height, body mass, body mass index, somatotype and body fat percentage.	1. Older age (p=0.002). 2. Taller height (p=0.006). 3. Greater body mass (p=0.001). 4. Vertical jump score (indication of strength; p=0.02). 5. Back extension ROM (indication of flexibility, p=0.013). 6. Ankle dorsiflexion ROM (indication of flexibility, p=0.013).

ROM, range of motion.

medical attention and physical complaints.[64–67] Additionally, using validated questionnaires that follow the same recommendations of injury should also be considered, for example, a modified version of the Oslo Sports Trauma Research Centre overuse injury questionnaire.[68] A consistent method to assess injury severity should also be developed that does not only rely on days lost to injury, as gymnasts often continue to train while injured.[44]

Additionally, there is a substantial lack of studies that focused on injuries in male artistic gymnasts. This review suggests that there may be differences between the injury patterns of female

gymnasts and male gymnasts, so more focused research on men's gymnastics is warranted. Greater quality information on recurrent injury rates would be beneficial especially considering that injury prevention methods differ depending on whether new injuries or recurrent injuries are the priority (ie, focusing on rehabilitating injuries fully before returning to former level of training). Lastly, more accurate risk factor research is needed and should be conducted prospectively and focus primarily on modifiable risk factors that could potentially be developed into successful injury prevention programmes.

CONCLUSION

Clinicians and coaches should be aware that gymnasts are at a greater risk of sustaining an injury as they grow older and taller, increase competitive levels and train longer hours. Future research should focus on increasing the quality of evidence by thoroughly reporting population characteristics while implementing consistent injury definitions and data collection methods. Additionally, greater information on the injuries of male gymnasts is needed, as well as higher quality prospective risk factor studies that place an emphasis on modifiable risk factors. Overall, more consistent and comprehensive injury reporting in competitive artistic gymnastics is needed to develop appropriate injury prevention strategies.

Acknowledgements This research is supported by an Australian Government Research Training Program (RTP) Scholarship.

Contributors All authors contributed to the original concept of this paper. RAC, EJB and WS designed the search strategy that RAC executed. RAC and WS independently undertook the process of inclusion/exclusion and assessment of bias. RAC extracted all data from the included studies. All authors contributed to the drafting and final approval of the manuscript. This work was undertaken by RAC as a component of her PhD under the supervision of authors EJB, NBB, DLP and WS.

What is already known

- Artistic gymnasts experience high rates of injury.
- Floor exercise is the apparatus most commonly associated with acute gymnastics injuries.
- The landing phase of gymnastics skills is when most gymnastics injuries occur.

What are the new findings

- Training at an advanced competitive level and performing at competitions are significant risk factors for gymnastics injury.
- Male artistic gymnasts sustain mostly injuries to the upper limbs, while females sustain lower limb injuries.
- The high contribution of overuse injuries has been overlooked in artistic gymnastics

How might it impact on clinical practice in the future?

- Injury prevention programmes may need to be tailored differently for male and female gymnasts.
- Clinicians should advocate for full rehabilitation of injuries prior to returning to training, as artistic gymnastics has high recurrent injury rates.
- Preventing overuse injury prevention should also be a focus, but there is a dearth of science as to how to achieve this goal.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

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